

THE LDEF ULTRA HEAVY COSMIC RAY EXPERIMENT

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SUMMARY

The LDEF Ultra Heavy Cosmic Ray Experiment (UHCRE) employed sixteen side viewing LDEF trays giving a total geometry factor for high energy cosmic rays of $30 \text{ m}^2\text{sr}$. The total exposure factor was $170 \text{ m}^2\text{sr y}$. The experiment is based on a modular array of 192 solid state nuclear track detector stacks, mounted in sets of four in 48 pressure vessels. The extended duration of the LDEF mission has resulted in a greatly enhanced potential scientific yield from the UHCRE. Initial scanning results indicate that at least 1800 cosmic ray nuclei with $Z > 65$ have been collected, including the world's first statistically significant sample of actinides. Post-flight work to date and the current status of the experiment are reviewed.

INTRODUCTION

The Long Duration Exposure Facility (LDEF) was deployed into a near circular orbit of 257 nautical miles altitude and 28.5° inclination by the Space Shuttle Chal-

lenger in April 1984. Almost six years later on January 12 1990 it was retrieved from a decaying orbit of approximately 180 nautical miles by the Space Shuttle Columbia and returned safely to Earth. The Ultra Heavy Cosmic Ray Experiment (UHCRC), which was mounted on the LDEF, was the largest array of cosmic ray particle detectors ever flown in space. It comprised a total of 192 solid state nuclear track detectors housed in 48 pressure vessels (at 1 atm of dry air) which were mounted in 16 of the LDEF experiment trays. Each stack was 20cm \times 26cm in area and contained mainly lexan polycarbonate interleaved with lead velocity degraders. The average Lexan equivalent thickness of the detectors was ~ 4.7 g/cm². (ref.1,2)

Initial inspection and analysis of the UHCRC hardware took place in the Spacecraft Assembly and Encapsulation Facility II at Kennedy Space Center (KSC) after which the experiment trays were removed and shipped to the European Space Research and Technology Centre (ESTEC) at Noordwijk.

ACTIVITIES AT KENNEDY SPACE CENTER AND ESTEC

The extended LDEF mission resulted in (i), a greatly increased sample of ultra heavy cosmic ray nuclei ($Z \geq 65$) and (ii), a wealth of information on meteoroid and space debris impacts on the UHCRC hardware. Activities at KSC were related to the latter investigation.

Impacts of size greater than 0.5 mm on the tray flanges were located by eye inspection. This was followed by photo documentation of all front and back tray surfaces. All sixteen Scheldahl G411500 thermal blankets of the UHCRC were inspected and the positions of impacts of size greater than 0.3 mm were recorded (ref.3). The blankets were then trisected and one third of each was archived at KSC while the remainder were shipped to ESTEC. A detailed report of the preliminary investigation of meteoroid and orbital debris impacts can be found in these proceedings (ref.4). Following an eye inspection of the upper surfaces of the cylinders and support frames all UHCRC hardware was shipped to ESTEC in the original containers.

At ESTEC a preliminary survey of the thermal covers was carried out by F. Levadou (ref.5) and further studies were reported at this conference (ref.6). The aluminium cylinders were removed from their trays in clean room conditions to avoid any surface contamination. Subsequently, the gas pressure within each cylinder was measured and it was found that no leakage had occurred. Six of the cylinders containing the detector stacks scheduled for post flight calibration were shipped to the Bevalac. The detector stacks were removed from the remainder of the cylinders and were shipped to Dublin for processing and analysis.

CALIBRATION OF DETECTORS

Pre-flight and post-flight calibration of the UHCRE detectors was carried out at the Berkeley Bevalac. In the preflight calibration which was undertaken in 1983, a number of stacks were exposed to 960 MeV/N uranium and 300 MeV/N iron and earlier (1979) to 122 MeV/N iron ions. Post flight calibration in May 1990 consisted of exposures to high energy uranium (920 MeV/N), gold (1150 MeV and 663 MeV/N), krypton (1496 MeV/N), iron (1690 MeV/N and 400 MeV/N). The aim of these calibrations was twofold; namely, (i) to determine the value of the constants in the expression used to determine the charge of the individual ultra heavy cosmic ray nuclei, (the etch rate is of the form $V_t = aJ^n$ where $J = f(\frac{Z_{eff}}{\beta})$, Z_{eff} is the effective charge and a and n are constants determined from calibration) and (ii) to determine whether there was any 'ageing' of the latent tracks of the particles during the LDEF Mission.

To date, measurements on the calibration data are at a very preliminary stage. Several uranium nuclei from the post flight calibration have been followed to their stopping points and their energy determined to a high degree of accuracy. The preliminary calibration data shown in fig.1f should be taken as a rough guide until further data is processed. It is shown here to indicate that the nuclei displayed are indeed ultra heavy and are in the charge region $70 < Z < 92$. The bar marked uranium in fig.1f shows the range of values expected for uranium nuclei of $\beta = 0.97$ (scaled up from measurements made at $\beta = 0.77$), using the standard model and assuming a value of n between 2.0 and 2.5, which corresponds to the limits found in previous experiments. The gold data was calculated using the same data and assumptions. Comparison of pre flight and post flight calibration data will be available later this year.

TEMPERATURE HISTORY OF UHCRE DETECTORS

The charge resolution achievable on the ultra heavy cosmic ray experiment is dependent on the temperature history of the UHCRE modules throughout the LDEF Mission (ref.7). The thermal design of the experiment was aimed at maintaining the temperature of the detectors below 30°C(86°F) and ensuring as narrow a band as possible between maximum and minimum values. Temperatures were measured at selected locations on the LDEF structure during the first 490 days of flight. These data were used in post flight analysis to update LDEF thermal models (ref.8). The in-flight parameter data has allowed an accurate assessment of the thermal model

used and the resulting temperature uncertainties have been reduced from a preflight value of $\pm 40^{\circ}\text{F}$ to less than $\pm 18^{\circ}\text{F}$. Table 1 shows the maximum and minimum temperatures calculated for the locations of all UHCRE trays along with the associated temperature band (Δ) for each case.

Table 1 - Maximum and Minimum Temperatures Experienced by UHCRE Trays
Tray Position Min Temp($^{\circ}\text{F}$) Max Temp($^{\circ}\text{F}$) Δ
on LDEF

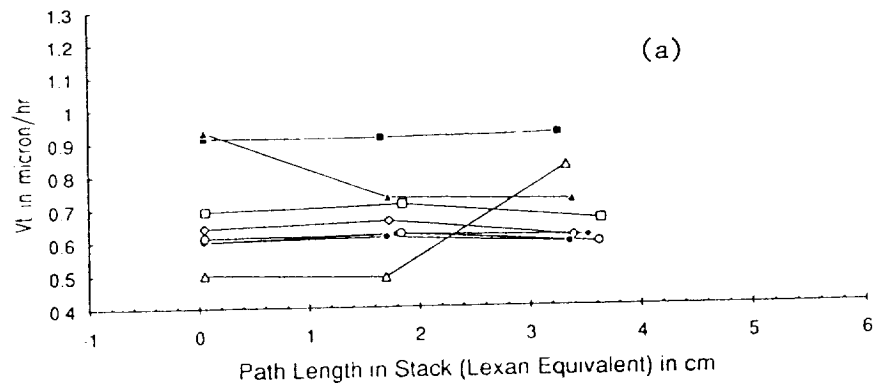
A2	48.7	86.9	38.2
A4	52.2	85.5	33.3
A10	50.6	82.5	31.9
B5	40.7	85.7	45.0
B7	37.9	90.1	52.2
C5	39.5	83.3	43.8
C6	34.8	91.6	56.8
C8	48.7	86.9	38.2
C11	38.9	80.9	42.0
D1	33.2	81.3	48.1
D5	37.5	82.4	44.9
D7	34.3	87.2	52.9
D11	36.7	77.4	40.7
E2	38.6	74.2	35.6
E10	41.4	71.6	30.2
F4	48.2	77.9	29.7

Further refinement of the LDEF thermal model is continuing but it is unlikely that the values in Table 1 will alter significantly (private communication, T. Sampair). Overall the temperature results are very encouraging. The mean temperature of the individual trays was well below the upper limit chosen as the basis for the thermal design. Furthermore the mean width of the temperature band was 41.5°F (23°C), smaller than expected on the basis of preflight analysis.

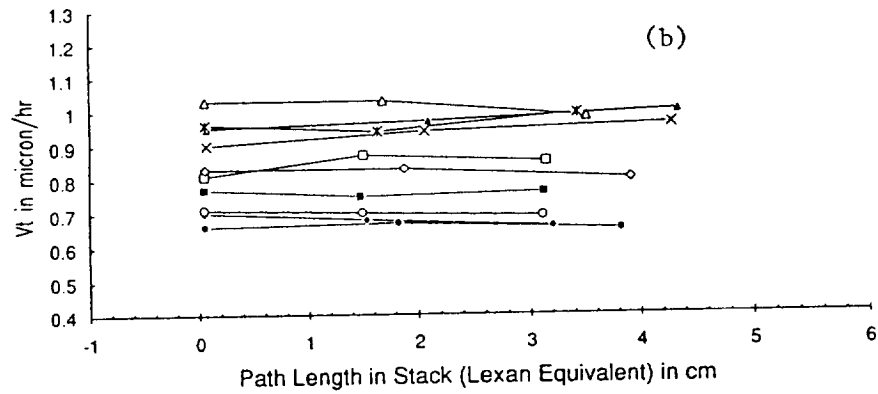
PRELIMINARY PROCESSING AND ANALYSIS

Three Lexan Polycarbonate detector sheets were removed from a number of the stacks and were etched for periods varying from 5 to 15 days at the standard

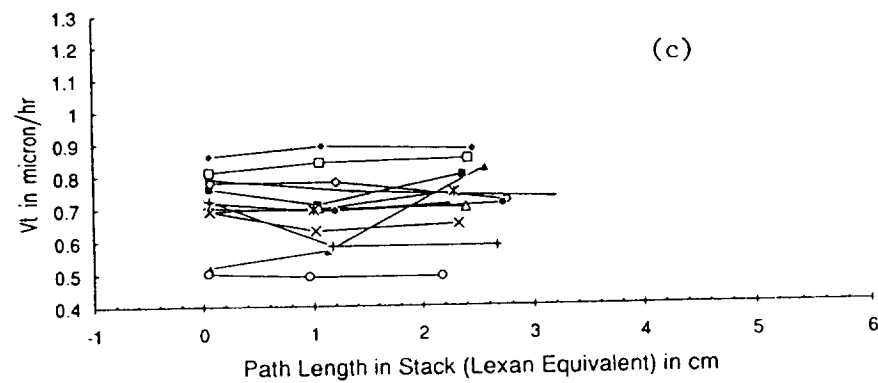
STACK NUMBER 61



STACK NUMBER 146

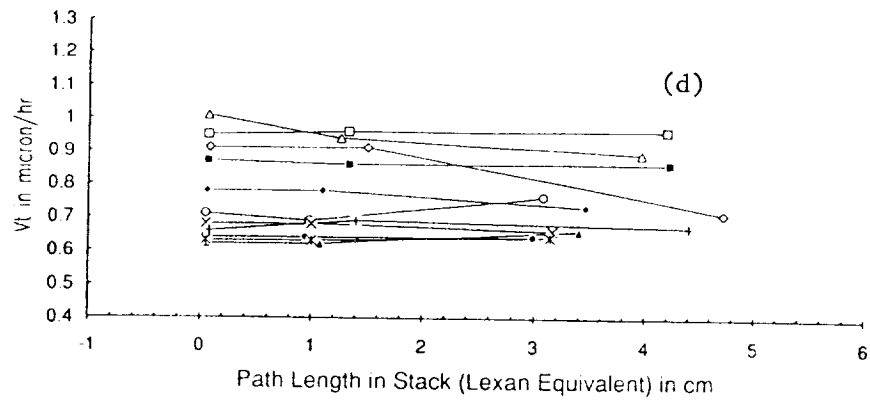


STACK NUMBER 157

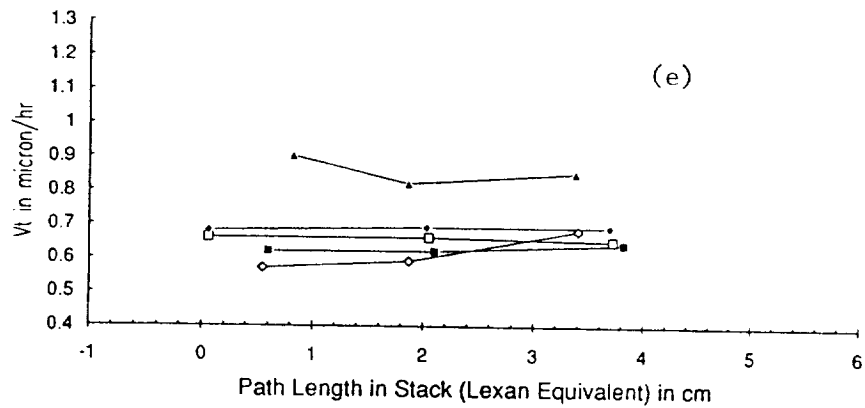


Figs. 1(a), (b), (c) : Etch rate as a function of depth in stack for ultra heavy nuclei observed in stacks 61, 146, 157 respectively.

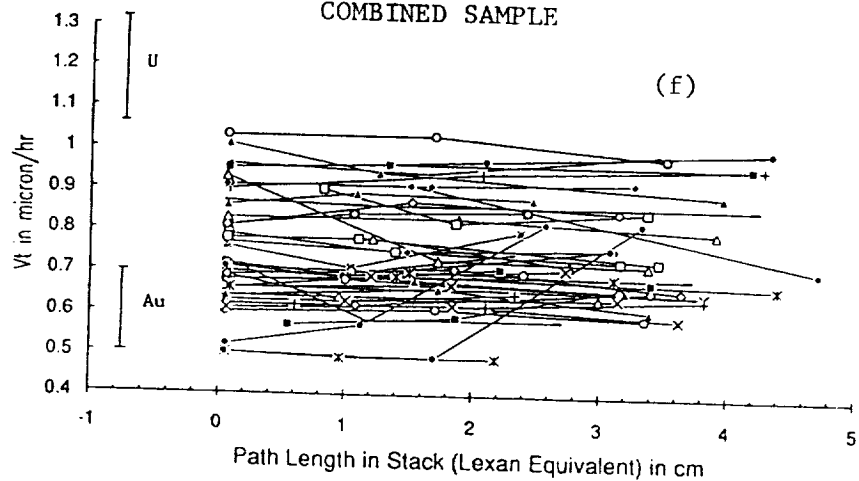
STACK NUMBER 181



STACK NUMBER 212



COMBINED SAMPLE



Figs.1(d),(e),(f) : Etch rate as a function of depth in stack for ultra heavy nuclei observed in stacks 181,212,and for the combined samples (a),(b),(c),(d) and (e). See text for explanation of Fig.1(f).

conditions of 40°C temperature and 6.25 N NaOH etchant. The sheets chosen were from the top, centre and bottom portions of these stacks providing a spread of path lengths varying from ~ 0.01 cm to ~ 4 cm in each case. Initial inspection showed that the surfaces of the sheets were of high quality and that the optical conditions for locating and measuring the tracks of ultra heavy nuclei were excellent.

Having located and measured the track parameters of a given nucleus in the top plate, its trajectory through the stack was estimated and the corresponding tracks were located and measured in the two lower parts of the stack. The number of ultra heavy nuclei observed ranged from 5 to 13 per stack indicating a total sample of >1800 collected during the LDEF mission.

Figure 1 displays the preliminary data obtained for ultra heavy nuclei in five of the UHCRE stacks. Plots of etch rate versus path length traversed in each stack is displayed for stacks 61, 146, 157, 181 and 212 (Figs. 1a, b, c, d, e resp.) These stacks were mounted in trays which were placed on rows six and eight of the twelve sided LDEF polygon (the leading edge was number nine).

It can be seen that for each stack the measured etch rates lie between $1.1 \mu\text{m/hr}$ and $0.5 \mu\text{m/hr}$ indicating a general consistency among the various sets of data. The different path lengths in the stacks for the centre and lower sections is due to different angles of incidence of the ultra heavy nuclei.

DISCUSSION

The initial post flight assessment of the UHCRE and preliminary data analysis indicate that the 69 month exposure in Earth orbit has achieved the major objectives of the experiment. The data shown in Fig. 1 display the characteristics of high energy ultra heavy nuclei as they traverse several grams of matter (ref.9). In the majority of cases there is no appreciable change in etch rate. Where a significant change does take place, the data is consistent with the occurrence of fragmentation in the stack. (In this regard it should be noted that, due to the inflight orientation of the LDEF, particles could enter the detector stacks from both top and bottom). The charge regime covered by the preliminary data as indicated by the quick look calibration measurements is consistent with that expected for relativistic cosmic ray nuclei in Lexan Polycarbonate (charge threshold $Z \sim 70$).

The temperature history of the detectors gives rise to optimism with regard to the registration temperature effect and the long term ageing of latent tracks. On the basis of the temperature regime experienced by the UHCRE trays, (91.6°F (33.1°C) to 33.2°F (0.7°C) respectively), the uncertainty in charge determination is expected to be less than two charge units according to estimates made from exposures to UH

nuclei at the Bevalac (ref.10). The impact of short term differential latent track evolution is currently under study.

The total number of ultra heavy nuclei collected during the mission is estimated to be ~ 1800 . Thus, the UHCRE has provided a sample which is approximately six times greater than the previous world sample and includes the first significant sample of cosmic ray actinides.

Initial assessment of the charge resolution achieved indicates that it would be possible to (i) resolve some of the important charge groups such as platinum and lead and (ii) determine the abundance of the actinides in the cosmic radiation. The actinide abundance is determined by the nature of r-process contributions to cosmic ray source material and early observations suggested the presence of freshly synthesised r-process material to account for a high value of the ratio of actinides to platinum-lead nuclides. However, the upper limit of 3% for this ratio found by Binns et al (ref.11) is consistent with solar system source abundances. (A somewhat larger value was reported at the same time by Fowler et al (ref.12)). The large UHCRE sample, combined with a charge resolution which is superior to that achieved in the early experiments with solid state nuclear track detectors, should clarify the situation.

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